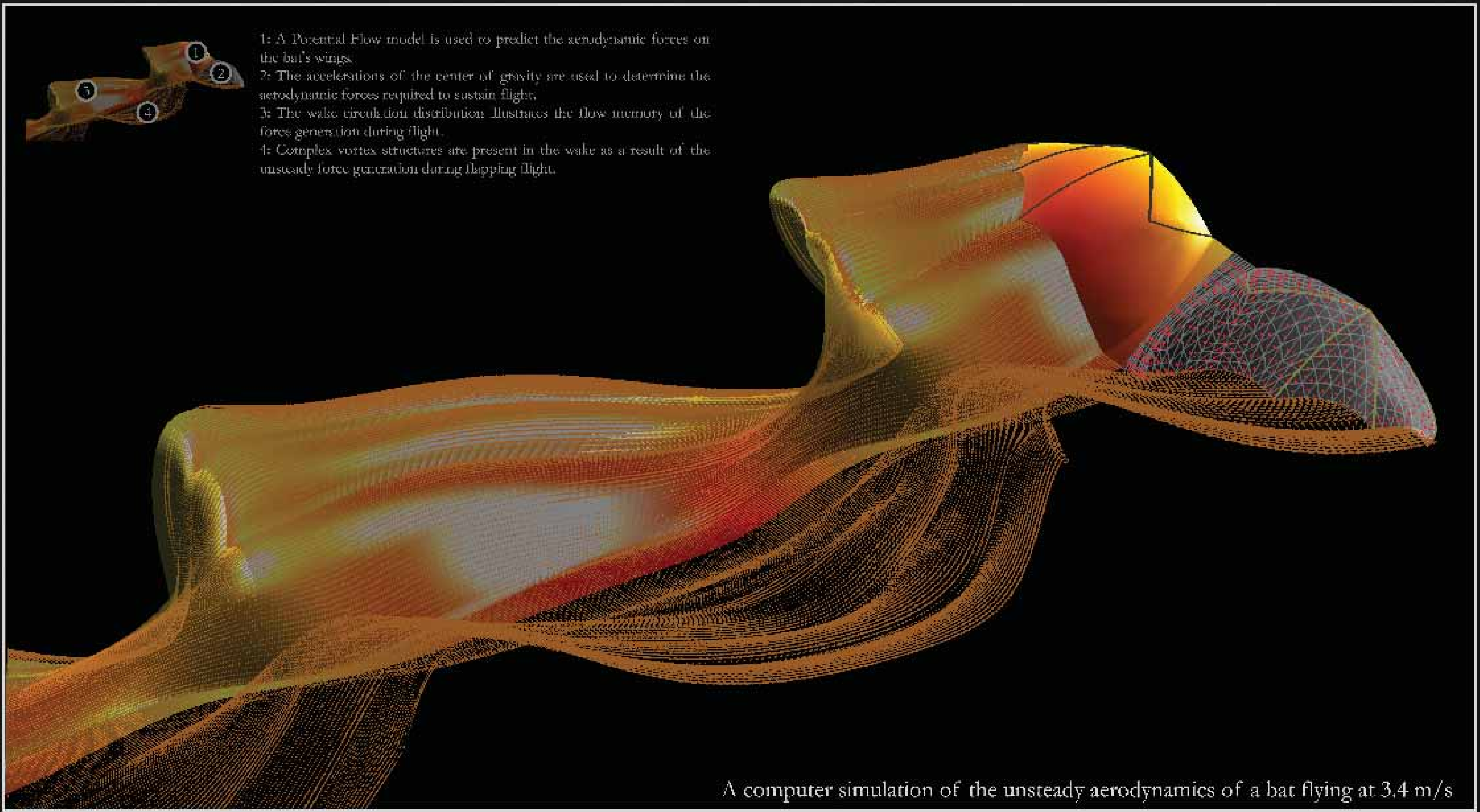
Modeling the flight of a bat

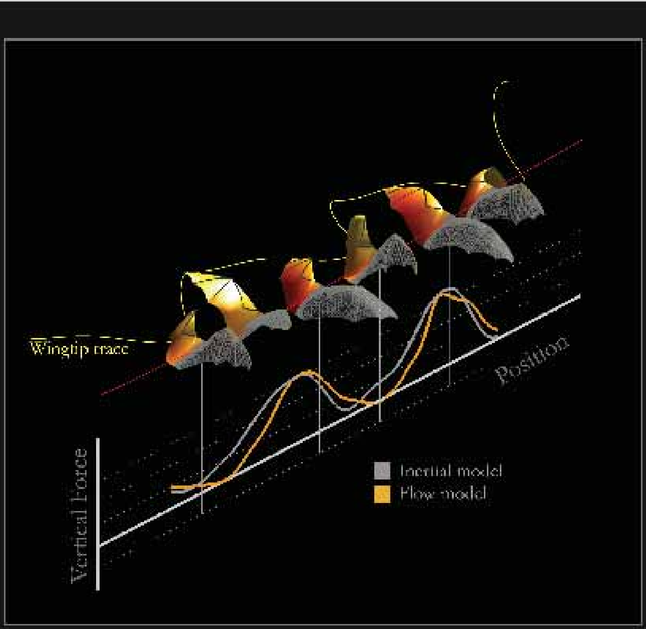


1: A Potential Flow model is used to predict the aerodynamic forces on the bat's wings.
2: The accelerations of the center of gravity are used to determine the aerodynamic forces required to sustain flight.
3: The wake circulation distribution illustrates the flow memory of the force generation during flight.
4: Complex vortex structures are present in the wake as a result of the unsteady force generation during flapping flight.

A computer simulation of the unsteady aerodynamics of a bat flying at 3.4 m/s

Bats are the only mammals capable of sustained flight. They are highly maneuverable and exploit efficient flight strategies. Today, we are using experiments and computer simulations to understand the details of the invisible air flow around the wings of a flying bat.

To construct a precise time-dependent model of bat flight, state of the art motion capture technology is applied to high speed stereo video of a bat (*Cynopterus brachyotis*) flying in a wind tunnel (above). The three-dimensional positions of the motion capture markers are used to construct the virtual geometry, which is used in the simulations. The surface model is used to compute the aerodynamics forces by applying a boundary element method Potential Flow model as well as a mass distribution inertial model. The vertical forces deduced from the observed accelerations are found to be in good agreement with those predicted by the flow model (right).



Professors Jaime Peraire and Mark Drela, and research scientist David Willis, are numerically simulating bat flight. Their collaboration with colleagues at Brown University on this topic may advance the design of highly maneuverable UAVs.

AEROSPACE COMPUTATION DESIGN & SIMULATION

Computation for simulation and optimization is essential to the design and operation of aerospace systems. For example, for its 787 program, Boeing credits computational engineering for requiring the building and testing of only seven prototype wings, compared to the 77 wings required for its predecessor, the 767.[16] Some engine design changes are now certified for flight safety based on simulations alone. Revenues from simulation and optimization software products are estimated to be in the billions of dollars, and the overall economic impact of these products is in the trillions of dollars.[17]

Despite these advances, there is consensus in the academic and institutional community that the field of computational science and engineering has yet to provide its full potential. As an illustration, consider digital flight: the modeling of aircraft aerodynamics throughout the entire flight envelope. Current high-fidelity computational fluid dynamics simulations are only reliable in on-design conditions (such as cruise) and for "standard" aircraft configurations. As a result, CFD is used for only a small number of operating points, while a combination of wind-tunnel experiments and low-fidelity models must be employed for the majority of flight conditions. In 10 to 15 years there will exist sufficient raw computational power to allow analysis of an aircraft's entire flight envelope using high-fidelity CFD. However, unless the reliability and automation of these methods is improved, accurate prediction of performance in all critical regions of the flight envelope will remain insurmountable. To address these challenges our department is leading the development of a new generation of flow solvers that represent a step change in both fidelity and automation. NASA, Boeing, and the U.S. Air Force are adopting preliminary versions of these codes.

> "Formidable challenges stand in the way of progress in simulation-based engineering science research."
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> NATIONAL SCIENCE FOUNDATION, 2006[15]

Ultimately, we must develop multidisciplinary simulation capabilities that include not only aerodynamic simulations, but also high-fidelity structural analyses, dynamics and control, and environmental performance. A grand challenge is incorporating these elements into a design and optimization setting that is also able to address the effects of uncertainties in modeling, operation, parameters, and requirements.

Multiscale materials modeling is another area of focus for the department. Because the connection between material microstructure and performance characteristics such as

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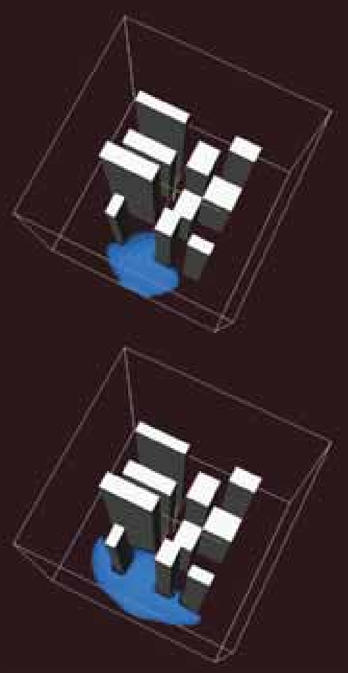
yield strength and ductility is generally unknown, material design has been based largely on empiricism. Multiscale materials modeling combined with high-performance computation provides a rational approach to material design. We are leading the application of this modeling paradigm to a variety of problems, for example, explaining the anomalous strength and ductility behavior of novel nano-structured metals. We have also been able to predict, for the first time, macroscopic material behavior, such as aluminum surface roughening in the forming process.

The department is also a leader in the analysis of blast effects on structures and humans and the conceptual design of blast-protective structures. As of March 2007, two-thirds of the 24,000 battlefield injuries suffered by soldiers in Iraq and Afghanistan were from bombs, and of these, 28 percent involved brain trauma.[18] We have developed a computational framework for understanding the injurious effects of blast waves on the human brain. The framework includes coupled blast-solid interaction analysis methods, tissue models, and high-fidelity anatomical models of the human head, and was developed in collaboration with the Defense and Veterans Brain Injury Center at the Walter Reed Army Medical Command. This capability is now being used to define the underlying mechanisms leading to brain injury and to develop injury mitigation strategies.

We are also making advances in real-time simulations — those performed at timescales less than the timescales of the physical problem. A challenge with applications to homeland security is to solve an inverse contaminant transport problem in an urban area represented by a grid of millions of cells, with limited measurements, in order to determine the probable upstream source of a contaminant release, and the

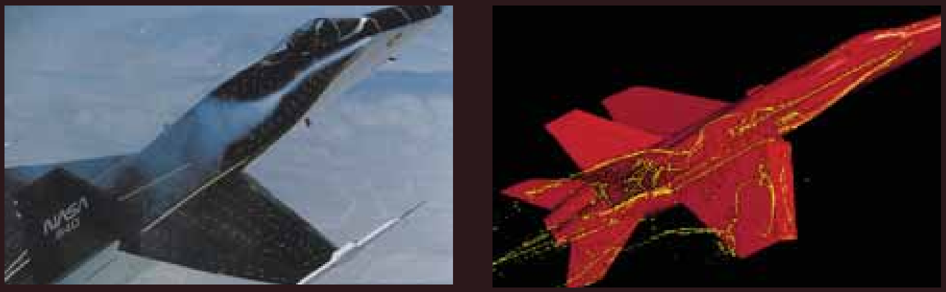


Field simulations of contaminant transport through complex domains take only seconds, using reduced-order models developed by Aero-Astro Professor Karen Willcox.

Incorporating these elements into a design and optimization setting that is also able to address the effects of uncertainties in modeling, operation, parameters, and requirements is a grand challenge.

Aero-Astro Aerospace Computational Design Laboratory students develop and use computational methods to study a range of problems. (WILLIAM LITANT)

potential downstream impact areas. This all must occur within a few minutes, to allow for emergency response. We are developing approaches to model reduction that enable the creation of accurate models that achieve these demanding real-time goals. Deployment of such methods in a practical setting means developing the ability to incorporate multidisciplinary models, quantify uncertainties, and achieve robust decision-making under conditions of uncertainty.



A flight test of the F/A-18 shows the dispersion of smoke particles that results from a vortex burst (left). Automatic identification and visualization of vortex cores, developed by Aero-Astro's Robert Haimes and Dr. David Kenwright of NASA Ames, reveal the same behavior in a CFD simulation (right). Visualization software developed by Haimes is used throughout the world.